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SCRIPPS INSTITUTION OF OCEANOGRAPHY LA JOLLA CA
W A NIERENBERG ET AL 14 APR 87

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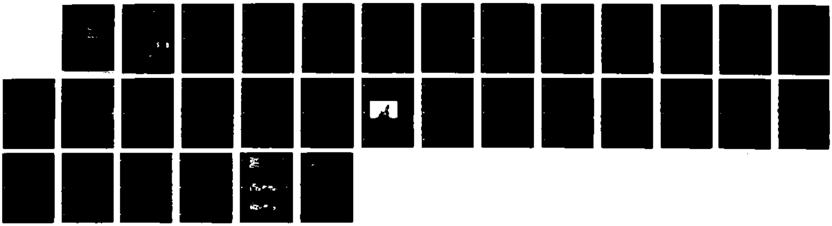

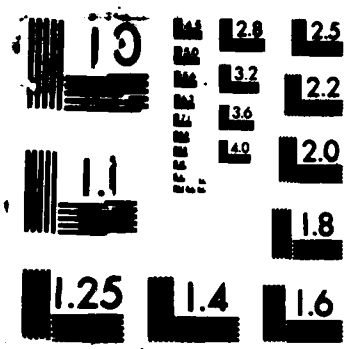
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First Semi-Annual Progress Report
for the
Scripps Institution of Oceanography's
University Research Initiative (URI)
entitled

"SCRIPPS OCEAN MODELING
AND REMOTE SENSING (SOMARS)"

87 4 17 094

FIRST SEMI-ANNUAL PROGRESS REPORT

FOR THE

SCRIPPS INSTITUTION OF OCEANOGRAPHY'S

UNIVERSITY RESEARCH INITIATIVE (URI)

ENTITLED

"SCRIPPS OCEAN MODELING AND REMOTE SENSING (SOMARS)"

Principal Investigator:

William A. Nierenberg

Co-Principal Investigators:

Catherine Gautier

James J. Simpson

Richard C. J. Somerville

Geoffrey K. Vallis

14 April 1987

INTRODUCTION

This is ~~the~~ first semi-annual report of the Scripps Institution of Oceanography's University Research Initiative (URI) entitled "Scripps Ocean Modeling and Remote Sensing (SOMARS)." The report consists of a set of unedited technical-financial statements prepared by individual scientists working on the URI. For your convenience, these statements are arranged in alphabetical order and separated by index tabs.

Should any questions arise concerning this report, please call them to the attention of:

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Scripps Insitution of Oceanography 3 March 1987

Interim Technical and Financial Report
University Research Initiative

Mark R. Abbott

Part 1. Technical Activity

Software development involving the use of a Mercury array processor in a Sun Microsystems workstation is continuing. The array processor includes a large library of standard mathematical and image processing routines. We are developing subprograms that will allow these packaged routines to be easily accessed by standard FORTRAN programs. We will use these routines to analyze a long time series of Coastal Zone Color Scanner imagery of the west coast of North America. In particular, we plan to examine the effects of irregular sampling (due to clouds, orbital characteristics of the satellite, and lost data passes) on the reliability of derived statistics.

Although the Sun has sufficient capabilities for image display and manipulation, standard analysis routines such as FFTs take several hours. The array processor should alleviate these problems.

Part 2. Financial Activity

Attached is a budget summary prepared by the Marine Life Research Group. Funds are being used to support P.M. Zion as a consultant on the array processor development activity, to support an account on the SIO remote user access center to the San Diego Supercomputer and to pay for LAN connection costs.

We expect that these activities will increase over the next six months as more CZCS data become available. The work will shift from development to actual analysis over this period.

Mark Abbott A-002

Marine Life Research   Fund Management for 3860   03/06/87

------ - -----   --------------------   Expires __/__/__

SUB	Allocation	Prior Expense	Current Expense	Total Expense	Lien	Balance
3 Supplies & Expense	-6576.00	257.00	0.00	257.00	10892.00	(4573.00)
4 Equipment	-1020.00	0.00	0.00	0.00	0.00	-1020.00
7 Other Expenses	0.00	2.68	0.00	2.68	0.00	(2.68)
Budget Total	-7596.00	259.68	0.00	259.68	10892.00	(3555.68)

(...) INDICATES A DEFICIT BALANCE.

From Sadie x4-3567

March 13, 1987

TO: J. SIMPSON

FROM: TIM BARNETT TB

SUBJECT: URI INTERIM REPORT

Work has progressed on two fronts:

(1) SAR stuff

The amount of wind wave refraction associated with various real ocean current systems has been computed. These theoretical values have been combined with uncertainties in SAR derived wave direction to perform an inverse sensitivity study. The study showed SAR can be used to estimate near surface current shears to within 5-20% given the right geometric relation in the wave-current interactions. The results, plus climatological wave statistics, suggest SAR can monitor the horizontal shear of the Gulf Stream. The large scale shear of the California current could also be estimated with similar accuracy for wave-current interaction angles near grazing incidence, i.e. generation region in the Gulf of Alaska or the mid-south Pacific.

Real SAR images across the Gulf Stream and for the Agulhas Current region have been obtained and will be processed to see if theory holds in practice. An algorithm for computing 2D wave spectra from the raw SAR data is now being applied to the data.

(2) OGCM sensitivity

A collaborative effort with John Bates is under way to estimate the sensitivity of the OGCM currently on the Alliant to variation in wind forcing. The idea is to run the model with three different, but real, wind fields and to compare the differences in model responses to the natural variability observed in the real ocean and internal model variability. Two of the three wind sets are on hand and the third has been ordered. There are a large number of exciting sub-projects that will arise out of this effort. Dr. Bates is taking the lead in this work.

(3) Funds

Most of the original allotment of funds for this work remain unspent at this moment. The money will be used largely for computer time to carry through the model comparisons and SAR wave spectral calculations.

TO: URI ECOM March 5, 1987

FROM: John Bates

SUBJECT: Report of technical and financial activity for the period 15 September 1986 through 15 March 1987.

Part 1 Technical Activity

During this contract period I have been working on acquiring and analyzing several different wind sets for the North Pacific Ocean. The aim of this work is to assess the uncertainties and error characteristics of different data sets since it is the surface wind stress that will drive the initial numerical models of the California Current. To date, two different winds sets have been acquired and are being analyzed. These are daily winds from FNOC on a 2 by 2 degree grid for the period 1975 through 1984 and twice daily winds from the NMC northern hemispheric model initialization on a 2.5 by 2.5 degree grid for the period July 1976 through June 1986. I am also in the process of acquiring a third wind set from the Army Corps of Engineers that will cover the last 20 years. Spatial and temporal differences are being examined and the different winds will be used to drive a simple quasi-geostrophic model of the ocean in order to establish the model sensitivity to the intitial uncertainties in the dynamic forcing.

Part 2 Financial Activity

I have spent the $2,000 allocated to me for PC equipment.

February 28,1987

To: J. Simpson, for URI ECOM
From: Bruce Cornuelle
Subject: Report on technical and financial activity

TECHNICAL

I have completed the inverse/mapping programs for a complete (or approximate) Kalman filter updating package, and the next step is to interface with Geoff Vallis' spectral model to begin updating simulations. The package is designed to accept most oceanographic observations, so no major modifications will be needed to start practical updating. Considerable effort has gone into the planning of the model/inverse interface, since it is important to preserve a separation between the inverse/mapping steps and the prediction steps in order to have compatibility with Bill Holland's models without major restructuring. The updating package uses a spectral model for the estimation, but the interface between the model and the estimation could do the transformations required to interface with a physical space model.

Some theoretical intercomparisons of assimilation schemes have also taken place in parallel with the package development efforts. While the Kalman filter is the solution to the time-dependent Wiener-Hopf equations for a linear(izeable) system, it is not necessarily the optimal assimilation technique for the general non-linear system with non-gaussian statistics. In addition, the necessity for re-calculating model parameter error covariance matrices in the Kalman filter makes the algorithm unattractive for oceanographic applications, particularly if primitive equation models are used. Some alternative techniques that have been explored are:

1) A direct non-linear fit to observational data within a block of space-time consistent with predictability limits. The model predictions would be controlled by varying the model initialization and forcing. This solves updating lock-on problems, and the intermediate model parameter uncertainty calculations are avoided, but non-linear optimization algorithms are by no means routine. One technique that shows promise is called "simulated annealing".

2) Optimal interpolation of the data within predictability limits to single model state vector; forecast, nowcast, or hindcast. The OI would use time-dependent covariances derived from Monte Carlo model simulations. While OI is well-understood, it is limited to linear prediction, and so broad ensemble averages of model realizations would give reduced predictabilities. If the model realizations are limited to

perturbations to a best-guess initial state, then the assimilation produced is closer to the Kalman filter, but without some of the model-space calculations. There is a possibility that the gravity-wave problems encountered in updating primitive equation models may be alleviated by this type of assimilation.

We need to understand how these different methods differ in practicality and efficiency, and so Geoff Vallis and I plan to try all three techniques and intercompare them.

FINANCIAL ACTIVITY

I have taken one month of salary out of the three available, and have been paying one-half of Lisa Stockinger's salary as a programmer. She has not really done any work for me yet, having been more of a systems programmer so far, learning the system of the Alliant computer and getting software packages and Holland's models running. I have spent only a small amount of the miscellaneous moneys allocated ($2K).

I hope that this is about what is needed for the report; if there are problems with this, let me know soon, and I can alter it before the deadline.

Regards,

Bruce

Bruce Cornuelle

TO: URI ECOM March 5, 1987

FROM: Catherine Gautier
John Bates

SUBJECT: Summary of technical and financial activity for the period 15 September 1986 through 15 March 1987

Part 1 Technical Activity

The hardware upgrade of our computer system is now almost complete. We have acquired a Rastertechnologies Model 180 display, additional disk capability for our Microvaxs and a floating-point accelerator for the VAX 11/750. We will acquire, in the near future, a hard copy device to be linked to the Rastertechnologies Model 180. The software upgrade of our system will take more time. We have hired a new programmer (B. Dealy) who is working full-time on collecting, assembling, and testing different NASA software packages to run under the Transportable Application Executive (TAE).

Remote sensing research activities under the URI have begun in several areas. These include the routine production of a sea surface temperature climatology consisting of at least one clear AVHRR pass per week beginning in December 1986 and continuing for the duration of the URI contract period. These data are being used to identify and follow the evolution of mesoscale eddies within the California Current. Second, we have begun to compute in differed real-time a local net surface radiation climatology from GOES satellite data from the individual components of the new shortwave and net longwave surface radiation. These computations encompass the area of Scripps pier for which an in-situ climatology will also be built. Third, we are processing the TOVS atmospheric sounder data in order to derive temperature and moisture profiles. This data will be used both in the calculation of the downwellilng longwave irradiance and estimate of the ocean surface evaporative heat loss. Fourth, we have collected GOES data for the first research cruise during which in-situ measurements will be made.

Part 2 Financial Activity

The financial activity for the remote sensing task has been divided into two portions; one for equipment and one for personnel, supplies, etc. In the equipment portion, approximately $12,000 minus cost of the hard copy device and applicable overhead was left in the account as of 1/31/87. Other liens have been logged against this account since 1/31 so it is anticipated that nearly all funds in this account will be used by 3/15/87. In the personnel account 51% of the allocation, or approximately $80,000 has been received. Of this amount we project that $22,500 of those funds minus applicable overhead will be left by 3/15/87.

March 4, 1987

MEMO

From: Peter Niiler P.N.
To: J. Simpson

Subject: Lagrangian Trajectories Data in the California Current (U.R.I.
15 Sept., '86 - 15 March, '87 - Interim Progress Report)

The following progress has been made on the reduction of Lagrangian drifter data in the California Current.

1. Position locations have been corrected for noise and filtered with 2-day running mean filter to produce low-frequency data series.

2. Lagrangian velocity time series have been computed from 2-day filtered series.

3. Statistics of variance and temporal autocorrelation function for the velocity time series have been computed.

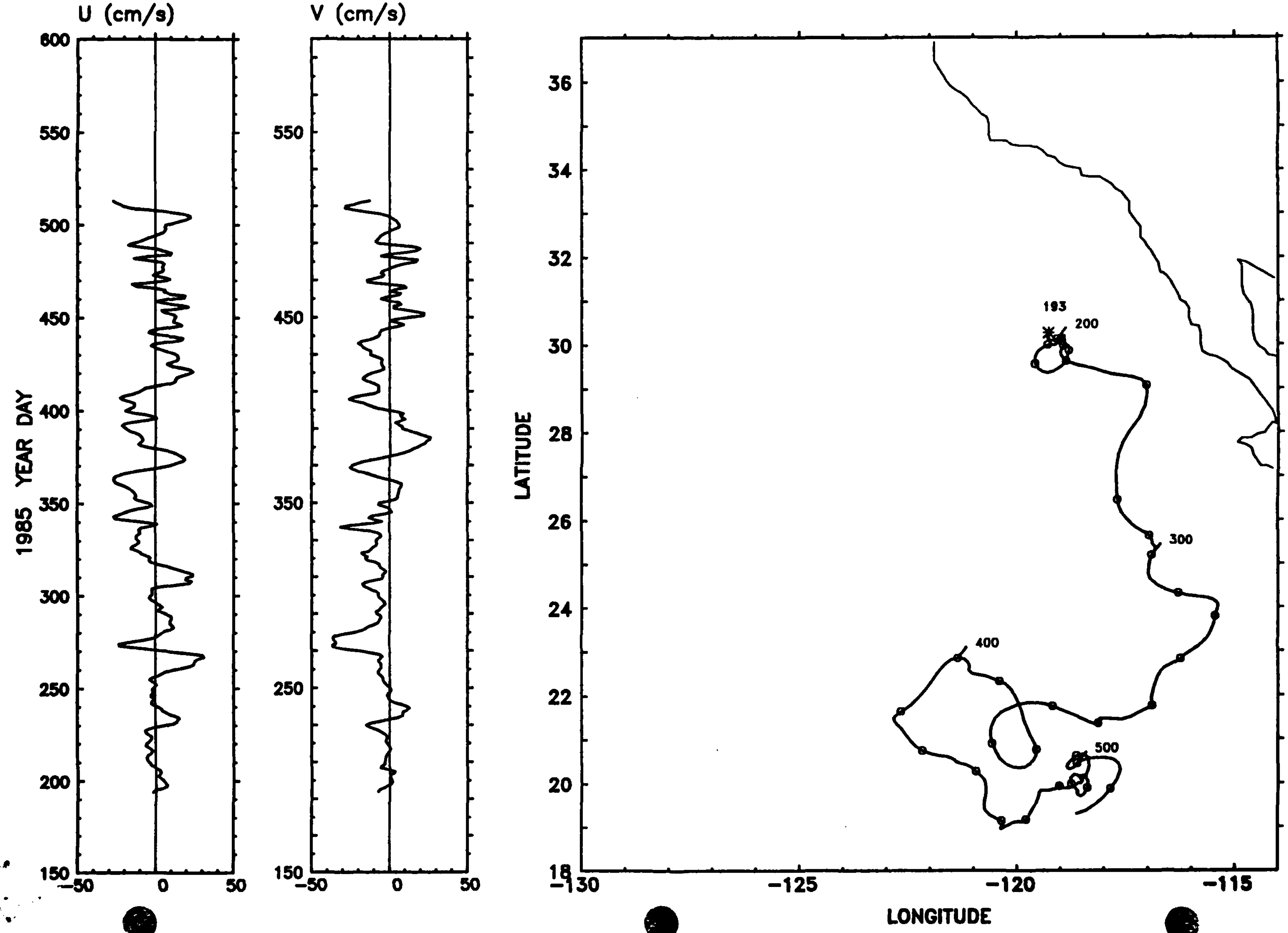
4. Plots of items (1), (2), (3), have been made for 29 drifters released into the California Current system in 1986 and 1986. (copies of examples enclosed).

5. Geographical binning of the data is in progress to produce Eulerian statistics.

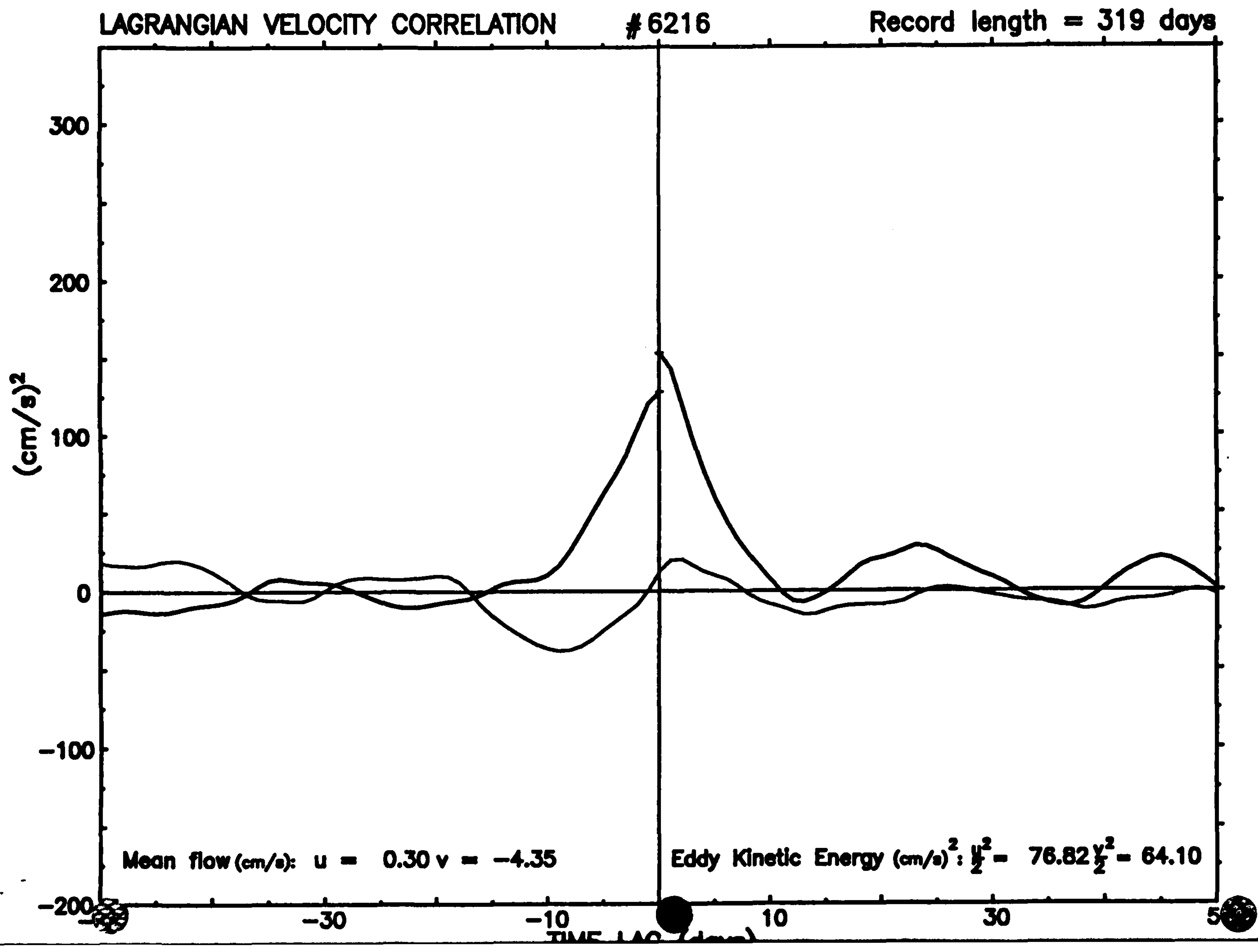
The following expenditures have been incurred: (initial allotment $13,645)

1.	Computer programmer salary......	$ 11,215.50
2.	Supplies & expenses	65.00
3.	Equipment......................	2.237.01
	TOTAL:	12,517.51
	Balance:	$ 424.71

#6216



U (cm/s)
V (cm/s)
1985 YEAR DAY
600
550
500
450
400
350
300
250
200
150
−50
0
50
LATITUDE
36
34
32
30
28
26
24
22
20
18
−130
−125
−120
−115
LONGITUDE
193
200
300
400
500



LAGRANGIAN VELOCITY CORRELATION
6216
Record length = 319 days
300
200
100
0
−100
−200
(cm/s)^2
Mean flow (cm/s): u = 0.30 v = −4.35
Eddy Kinetic Energy (cm/s)^2: $\frac{u^2}{2}$ = 76.82 $\frac{v^2}{2}$ = 64.10
−30
−10
10
30

Semi-Annual Report for Scripps URI

15 September 1986 - 15 March 1987

James J. Simpson

I. SCIENTIFIC ACTIVITY

The in situ/remote sensing activity so far has had three thrust areas:

1. Integrated Systems Development
2. Experiments at Sea
3. Image Analysis.

1. Integrated Systems Development

An integrated sea-going in situ/remote sensing system was developed to provide a four-dimensional representation of the ocean-atmosphere environment in quasi-real time. This was achieved through a network of computer nodes (Figure 1A). The ROOT of this system is a HP 9000/560 computer which has complete image processing capability. Image analysis, data merge and the initial steps of data assimilation can be done at sea at the ROOT. Ground-truth data (e.g., radiometric sea surface temperature, phytoplankton pigment concentration) for remotely-sensed data are acquired, processed and displayed in real-time using an UNDERWAY node which consists of an HP VECTRA, a general purpose signal conditioner and data logger (HP 3852A), and a variety of transducers (e.g., dew point hydrometers, long-wave radiometers). Interior ocean or atmospheric data (e.g., CTD, radiosonde) are acquired and processed using a PROFILE node which consists of an HP VECTRA, various standard interfaces and specialized instrumentation. We anticipate linking the sea-going system (Figure 1A) via a satellite communications link (Figure 1B) to the Scripps central computer facilities (Figure 1C) where the process of data assimilation can be completed. The Tactical Environmental Support System (TESS) and several operational Navy commands have expressed interest in this approach towards a complete four-dimensional specification of environmental conditions.

2. Experiments at Sea

Our first URI cruise was conducted from 14 February to 23 March 1987 on USNS de Steiguer. This cruise consisted of four legs and was done in cooperation with the Naval Ocean Systems Center (NOSC) and the Naval Environmental Prediction and Research Facility (NEPRF). Highlights of the cruise are:

a. The UNDERWAY and PROFILE nodes developed for the URI program achieved about a 98% high quality data return rate.

b. Four (4) different eddies were mapped during the experiment. Those, plus three other eddies mapped during different experiments, all contained a core of California Undercurrent water. Hence, it is likely that the offshore mesoscale eddy field in the California Current System is associated with a baroclinic instability of the subsurface California Undercurrent. This makes eddies in the California Current System rather different from rings in the Gulf Stream.

c. The decay sequence of one of the eddies was measured. Conservatively, the kinetic energy of this eddy decreased by 60% over the period of the experiment (Figure 2). The decay and/or diffusion of the associated frontal structure also was measured with both in situ and remotely-sensed techniques.

d. A unique data set consisting of radiometric sea surface temperature, radiative flux measurements, turbulent flux measurements, atmospheric radiosondes, AVHRR, TOVS, GOES, and VAS data also was collected. These data can be used to: 1) examine the effects of atmospheric humidity on both AVHRR and GEOSAT data, and 2) improve current algorithms for satellite-derived estimates of sea surface temperature, long-wave radiation and short-wave radiation.

e. NOSC took continuous Doppler Acoustic log velocity profiles throughout the experiment and during leg 3 successfully deployed a continuous vertical profiling pumping system.

f. NEPRF took radiosonde data.

The next scheduled URI cruise will take place 2 - 15 September 1987. Use of State of California ship time for this cruise has been approved by SIO Director E. Frieman.

3. Image Analysis Activity

The image analysis activity has consisted of two separate components: a) system development, and b) image analysis.

a. System Development:

For the past six months, we have built a hardware/software configuration suitable for general purpose image analysis both in the laboratory and at sea. The hardware configuration is comprised of an HP 9000/560 and associated peripherals The software configuration uses UNIX as the operating system. A set of generalized image processing tools (e.g., convolution methods, FFT, enhanced graphics) now is fully operational. In addition, software hooks have been installed in the system (e.g., generalized image input/output utilities, parsors, etc.) which enable sophisticated higher-level scientific applications code to be written in an efficient way.

b. Image Analysis:

Presently we are implementing algorithms to produce minimum mean square error grid estimates (i.e., objective maps) of sea surface temperature, plant pigment concentration, surface velocity and dynamic height from satellite observations (AVHRR, CZCS, and GEOSAT). Our ultimate goal is to utilize methods of artificial intelligence and pattern recognition to estimate the statistics of the eddy field in the California Current. Two prerequisites necessary to achieve this goal are: improved cloud removal algorithms for AVHRR and CZCS and efficient application of objective mapping techniques to satellite data bases. We plan to implement cloud removal for both day and night using methods analogous to those presented by McClain. Also, the data base obtained from our February-March 1987 cruise is robust enough to objectively determine the best method for estimating SST from satellite brightness temperatures and the effects of atmospheric humidity on GEOSAT estimates of dynamic height. We have implemented universal kriging methodology as the basis for our objective mapping of satellite-derived products.

Initially, we have assumed that the covariance function is a Gaussian function. With this functional form of the covariance matrix specified, it only remains to specify four image parameters: the TRUE signal variance, the x decorrelation scale, the y decorrelation scale, and the noise variance. These parameters can be estimated from a knowledge of the structure function of the image. Computational constraints require that we subsample the image. This subsampling, however, does not affect our ability to objectively resolve mesoscale features (10-200 km). Our first applications of these techniques will be on the four-month set of images (AVHRR and GEOSAT) which precede, cover, and follow the February-March 1987 cruise.

II. PUBLICATION

The publications listed below have resulted, at least in part, from URI-related work:

a) Simpson, J.J., C.J. Koblinsky, J. Pelaez, L.R. Haury, and D. Wiesenhahn, 1986: Temperature - plant pigment - optical relations in a recurrent offshore mesoscale eddy near Point Conception, California. J. Geophys. Res., 91(C11): 12,919-12,936.

b) Haury, L.R., J.J. Simpson, J. Pelaez, C.J. Koblinsky, and D. Wiesenhahn, 1986: Biological consequences of a recurrent eddy off Point Conception, California. J. Geophys. Res., 91(C11): 12,937-12,956.

c) Lynn, R.J., and J.J. Simpson, 1987: California Current System - The seasonal variability of its physical characteristics. J. Geophys. Res., accepted for publication and in press.

III. COOPERATION WITH NAVY LABORATORY

1. Naval Environmental Prediction and Research Facility (NEPRF)

NEPRF and I have cooperated on measurements of atmospheric structure during our February-March 1987 cruise. We plan to jointly use these data, and other data taken during the cruise, to evaluate atmospheric correction algorithms for satellite data and to estimate surface fluxes of heat and momentum.

2. Tactical Environmental Support System (TESS)

I will actively participate on the TESS Review Board (TRB). This has occurred as a direct result of systems work done as part of the Scripps URI.

3. Naval Ocean Systems Center (NOSC)

The 40-day cruise on USNS de Steiguer (14 February - 23 March 1987) was a cooperative effort between NOSC and my laboratory. It is anticipated that both groups will work cooperatively on the analysis of data. Additional joint cruises with NOSC in support of URI activities are a distinct possibility.

4. Operational Commands

Several operational commands have requested technical assistance in implementing an integrated image analysis - *in situ* data acquisition system similar to the one I put together for the URI. Currently, I am working with these commands on an individual basis.

IV. ADMINISTRATIVE

During the past year I have served as Secretary of the Executive Committee. As such, I have been the principal liaison between the Executive Committee and UCSD Contracts and Grants, CalSpace Contracts administrative personnel, the ONR Resident Representative Mr. R. Bachman, and ONR Washington. Preparation of reports, budget reviews, individual investigator requests for budgetary reprogramming authority, and the like constituted the major part of this administrative function.

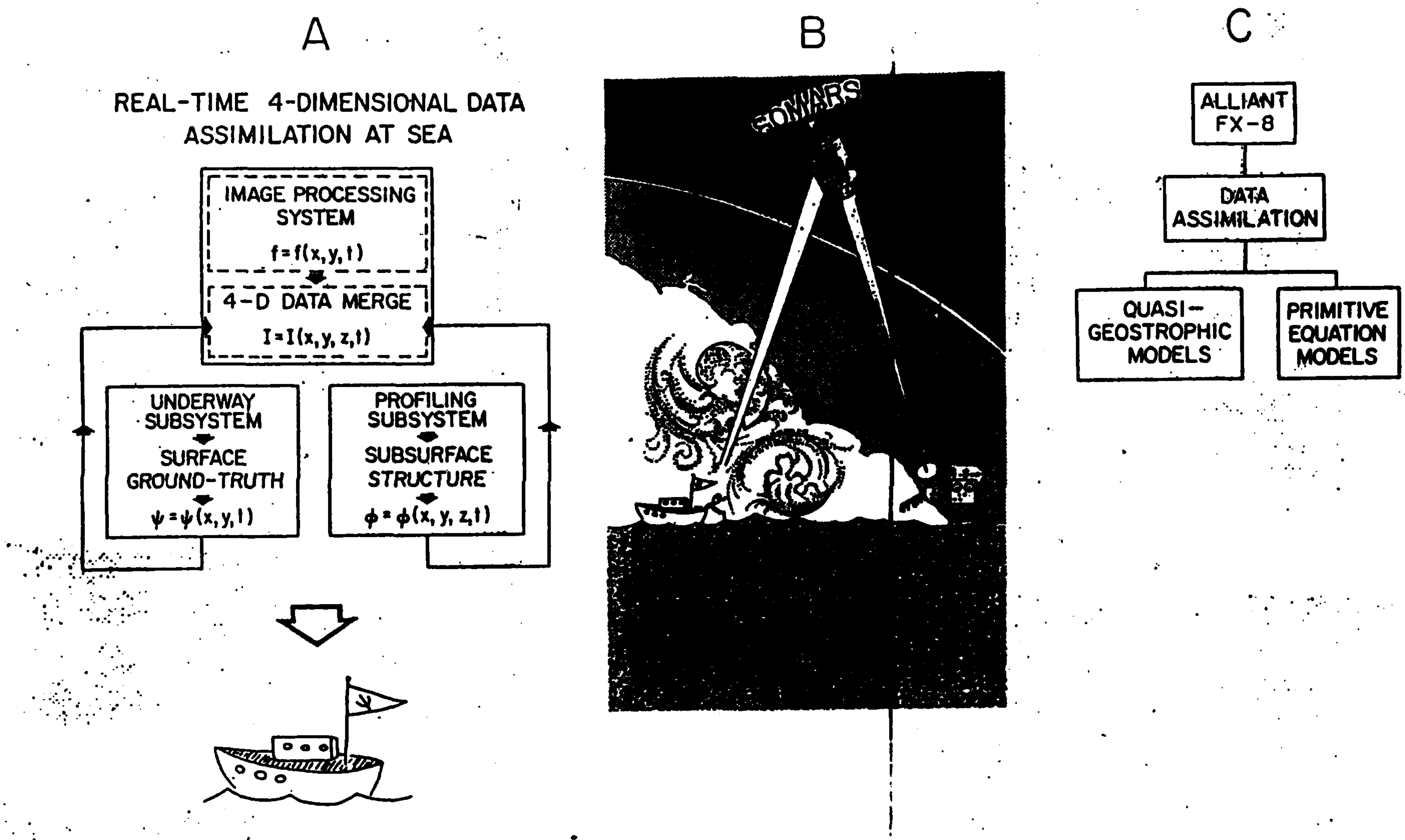
V. FINANCIAL

The main equipment purchased over the period has been: the image analysis system, equipment for the PROFILING node, and equipment for the UNDERWAY node. These three items were line items in the budget.

A postdoctoral research assistant has been working with the project since 15 January 1987.

Salaries, sea-pay differential, overtime and benefits associated with the 40-day cruise also constituted a major budget item.

A full-time programmer has been selected to work on the implementation of pattern recognition / artificial intelligence concepts in the area of remote sensing.



Block diagram of real-time 4-dimensional data acquisition, merge/assimilation system (Figure 1a) with satellite link (Figure 1b) to land based computational center (Figure 1c) [from Dr. J. Simpson/SIO].

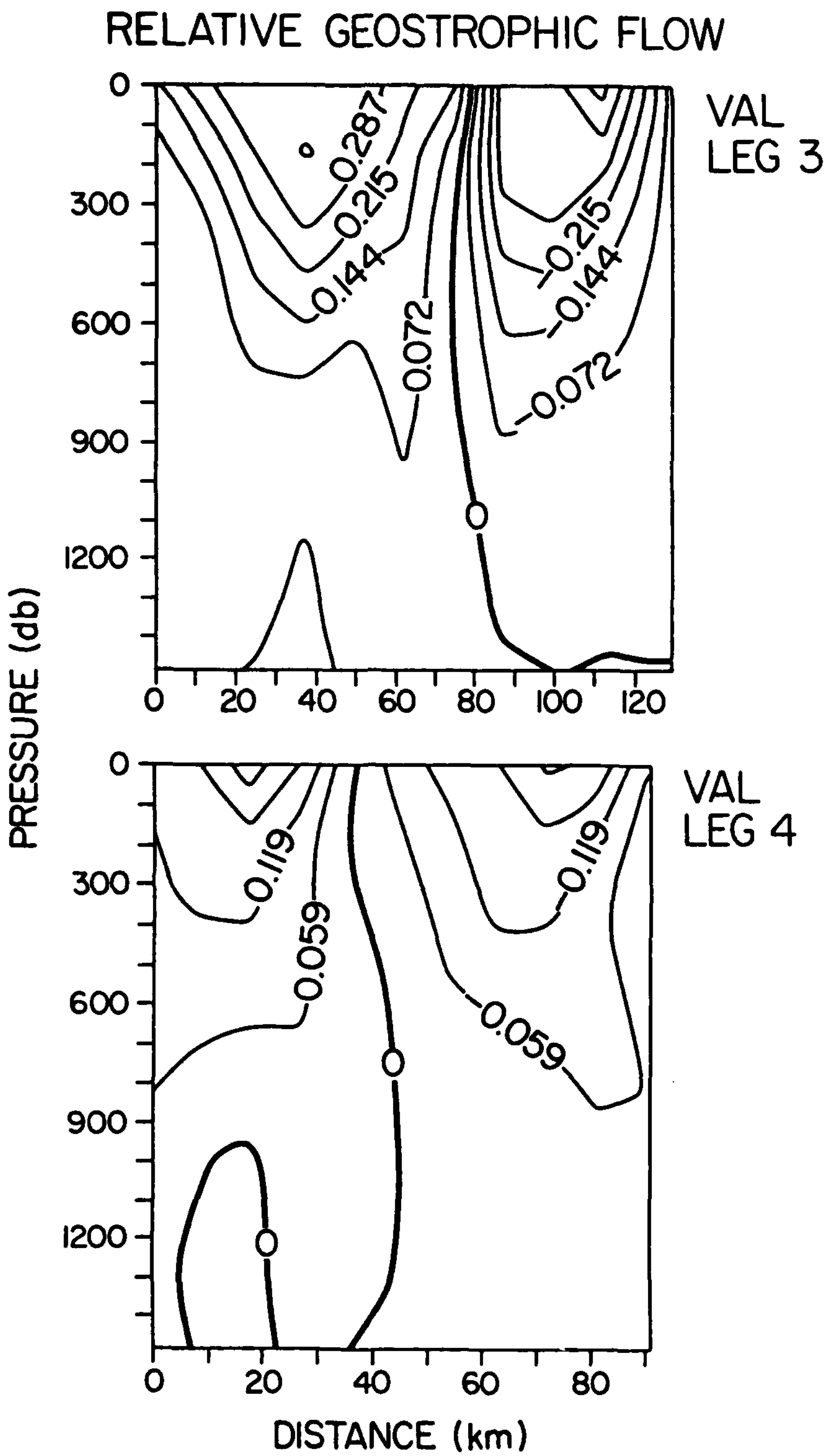


Figure 2. Consecutive EW transects of geostrophic velocity taken through one of the eddies observed during the URI VAL cruise 14 February - 23 March 1987.

LA JOLLA: SCRIPPS INSTITUTION OF OCEANOGRAPHY
CLIMATE RESEARCH GROUP

April 8, 1987

MEMO TO: James J. Simpson

SUBJECT: URI Progress Report

Early work has focused primarily on furthering our understanding of the concepts involved in a one-dimensional mixed-layer model of the ocean. In order to increase our knowledge of these concepts a preliminary mixed-layer model has been built. This preliminary model is a simplified version of the mixed-layer model physics found in Niiler and Kraus (1977). This simplified model is not intended as a substitute for an accurate ocean mixed-layer model, but rather as a tool to aid in understanding mixed-layer dynamics. After sufficient time has been spent studying the preliminary model results, a full-scale mixed-layer model will be built utilizing all of the appropriate physical concepts presented in Niiler and Kraus (1977). Once this mixed-layer model is operational, we intend to couple it to be a one-dimensional atmospheric radiative-convective model. The radiative-convective model has already been developed and applied to study cloud feedbacks in a CO2-rich atmosphere (Somerville and Remer, 1984; Somerville and Iacobellis, 1987). The coupled ocean-atmosphere model will be used in studies of the Summer monsoon of the Indian Ocean and Arabian Sea. In particular the model will be used to investigate the role air-sea interactions and surface heat fluxes have in the onset and maintenance of the monsoon.

Richard Somerville /CB
Richard Somerville

SIO URI SEMI-ANNUAL TECHNICAL REPORT

EXPERIMENTS ON THE ASSIMILATION OF ALTIMETER DATA INTO A QUASI-GEOSTROPHIC, EDDY-RESOLVING, NUMERICAL MODEL

by

W. B. White

and

C.-K. Tai

Scripps Institution of Oceanography

University of California, San Diego

A-030

La Jolla, California 92093

February 13, 1987

Descrete sequential estimation (Kalman, 1960) is a method of updating model data with observations in optimal fashion. It has two powerful attributes in its theoretical application. First, it allows each observation to influence the updating of every location in the model first guess field. Second, it allows the error covariance structure (i.e., covariance of the difference between the observations and the model first guess field) to be updated at each time step. There does exist one serious drawback, however; these most powerful attributes lead to impossible computational requirements in the present application.

A number of investigators have, in special application, made simplifications to the most general form of descrete sequential estimation, reducing its computational intensity to more reasonable levels. Parrish and Cohn (1985) have used the approximation that forcast errors at distant points are uncorrelated, allowing the updating procedure to be regionalized. Balgovind *et al.*, (1983) determined that the error covariance function was, under certain conditions, spatially homogeneous.

Actually, descrete sequential estimation is a variation of linear, least-squares, estimation which forms the basis for optimum interpolation and other linear optimal estimation procedures (Miller, 1986). Understanding the similarity and differences between these two variations of linear least-squares, estimation allows the discrete sequential estimation formalism to be understood juxtaposed with optimum interpolation formalism. It further allows experience gained with working with optimum interpolation in the oceanic application to be transferred readily to related issues in discrete sequential estimation, addressing the most serious limitation to its application to practical problems; i.e., its computational intensity.

In the formalism of optimum interpolations, a set of weights, α_i, is determined, constituting a space/time filter; once determined, these weights operate upon observation residuals, z'_i (i.e., the diference between the observation z_i and the climatological mean field $\overline{z}_i$) about the grid node to produce an interpolated residual value, $\hat{z}'$, at the grid node; i.e.,

$$\hat{z}' = \sum_{i=1}^{N} \alpha_i z'_i \tag{2.1}$$

where, practically speaking, N is the number of observations within a decorrelation length sale of the grid node. This can be rewritten in another form

$$\hat{z} = \overline{z} + \sum_{i=1}^{N} \alpha_i (z_i - \overline{z}_i) \tag{2.2}$$

where z_i is the observation value about a grid node and $\overline{x}_i$ is the climatological mean value at the observation location i. In this form, $\overline{x}$ can be considered the first guess estimate for the true value, x, and $\hat{x}$ is the updated estimate of x at a grid node due to the presence of observations, z_i, about the grid node that differ from this first guess field $\overline{x}_i$, about the grid node.

In the formalism of discrete sequential estimation, a set of weights, β_i, is also detrmined, constituting a space/time filter; once determined, these weights operate upon observation residuals, z_i' (i.e., the difference between the observation z_i and the first guess field, $\tilde{x}_i$), about the grid node to produce an updated value, $\hat{x}$, of the true value, x, at the grid node; i.e.,

$$\hat{x} = \tilde{x} + \sum_{i=1}^{N}\beta_i(z_i - \tilde{x}_i) \ . \tag{2.3}$$

The difference between (2.3) and (2.2) is that in (2.2) the estimation of $\hat{x}$ at the grid node is not sequential, whereas in (2.3) it is; i.e., $\overline{x}_i$ does not depend upon $\hat{x}$ as time and space progress, whereas $\tilde{x}$ is replaced by $\hat{x}$ as time and space progress. The sequential aspect proceeds with the expectation that eventually $|z_i - \tilde{x}_i|$ converges to some noise level, as the model first guess field, $\tilde{x}$, coverges toward the observation field, z_i. This is not expected in the optimum interpolation formalism, where the synoptic observation field, z_i, will always, in general, differ from the climatological first guess field $\overline{x}_i$.

The determination of the set of weights, α_i, in (2.2) given to the differences between the observations and the first guess field follows from linear least-squares, estimation, where the true expectation value of the squared error between the updated field and the true field is minimize with respect to the weights; i.e.,

$$J = E\left[(x' - \sum_{i=1}^{N}\alpha_i z'_i)(x' - \sum_{j=1}^{N}\alpha_j z'_j)\right]$$

$$\frac{\partial J}{\partial \alpha_i} = E2\left[\sum_{i=1}^{N} z'_i(\hat{x}' - \sum_{j=1}^{N}\alpha_j z'_j)\right] = 0 \tag{2.4}$$

where the true value x' in (2.4a) is replaced by the updated grid node value, $\hat{x}'$, in (2.4b). This leads directly to

$$R_{o,i} - \sum_{j=1}^{N}\alpha_j \ R_{i,j} = 0 \quad (i=1,\dots,N) \tag{2.5}$$

for data points N lying within a decorrelation length scale from the grid node. $R_{o,i}$ is the covariance [i.e., E $(z'_i \hat{x}')$] between the grid point residual value, $\hat{x}'$, and the surrounding observation residuals z'_i. $R_{i,j}$ is the covariance [i.e., E $(z'_i z'_j)$] between the observation residuals themselves. Solution of (2.5) leads to the determination of the set of weights, α_i, for each observation i about the grid node.

The determination of the set of weights, β_i, in (2.3) given to the differences between the observations and the first guess field follows from a similar set of procedures leading from (2.4) to (2.5), with the added assumption that no error exists between the observation, z_i, and the true field x. This leads directly to

$$P_{o,i} - \sum_{j=1}^{N} \beta_j \, P_{i,j} = O \quad (i=1,\ldots,N) \tag{2.6}$$

for data points N lying within a decorrelation length scale from the grid node. $P_{o,i}$ is the covariance [i.e., E $(z'_i \hat{x}')$] between the grid point residual value (i.e., $\hat{x}'_i$, the difference between the true value at the model grid node and the first guess field) and the surrounding observation residuals (i.e., z'_i, the difference between the observations and the first guess field). $P_{i,j}$ is the covariance [i.e., E $(z'_i z'_j)$] between the observation residuals themselves. Solution of (2.6) leads to the determination of the set of weight, β_i, for each observation about the grid node.

In the case of optimum interpolation $R_{i,j}$ is the covariance of the residuals between the first guess climatological field and the observations. In the case of discrete sequential estimation, $P_{i,j}$ is the covariance of the residuals between the first guess model field and the observations. In the optimum interpolation formalism the covariance structure is usually determined *a priori* over a region in which these statistical moments are considered homogeneous and stationary. Generally, in the optimum interpolation formalism, not enough observations (i.e. degrees of freedom) exist about each grid node at each time step to provide a reliable estimate of the covariance structure; if enough observations were available for this task, it can be shown that optimum interpolation reduces to a block averaging procedure for the observations close to the grid point. In the discrete sequential estimation formalism, the covariance structure itself must be continually updated, since the sequential aspect of both the model integration and the updating itself consistently changes the first guess field. Yet, this updating of the covarance structure in discrete sequential estimation suffers from the same problems as would occur in optimum interpolaton; i.e., their often are not enough observations to update both $P_{i,j}$ and $P_{o,i}$ at each location and at each time step upon completion of the updating procedure. Yet, the updating procedure must go forward; it is sensible, however, to update

$P_{o,i}$ and $P_{i,j}$ not every time step, but rather when enough observations have accumulated so that the updating of $P_{o,i}$ and $P_{i,j}$ is not ill-conditioned. Another approach is to not update the covariance functions at all, assuming them to be of constant form. In this case, the discrete sequential estimation reduces to optimum interpolation (Miller, 1986).

The updating of the covariance function both before and after every time step makes discrete sequential estimation computationally intensive. Discrete sequential estimation is also computationally intensive because each observation is allowed to have influence upon every grid point in the field. In oceanic application, this is nonsense (i.e., first guess errors the California Current do not affect first guess errors in the Kuroshio Extension within the same time step). Therefore, following experience in optimum interpolation, the number (N) of forecast errors (i.e., $x_i - \hat{x}_i$) that are allowed to affect a grid node are taken to be only those that fall within a search radius equal to the decorerlation scale of the covariance of the forecast errors. This is consistent with what is done in optimum interpolation and has already been attempted by Parrish and Cohn (1985). This markedly reduces the computational intensity, since at each time step most of the grid nodes will not be updated, except by virtue of the time/space spreading of earlier updates by the numerical integration itself.

In response to the necessity for reducing the computational requirements in 4D model/data assimilation, the following set of numerical modeling experiments will be conducted. A wind-driven, eddy resolving, numerical box model, driven by the Hellerman mean wind stress is operated, initialized with the steady state Sverdrup solution. This is driven for one year and produces an eddy field in the western boundary current extension. It represents the control model run. From this initial model integration, dynamic height difference data have been extracted along the exact repeat orbits of GEOSAT at the approximate sampling rate observed (i.e., 25 km along track; tracks separated by 140 km and 17 days), representing the dynamic height difference observations that GEOSAT would detect in the real ocean. This initial model run is repeated, again driven by Hellerman winds, but with different initial conditions so that the eddy activity in the western boundary extension evolves during the second model run differently from that in the initial model control run. Then a third model run is conducted with this same wind forcing, but assimilted with GEOSAT dynamic height difference data from the initial model control run using a modified version of discrete sequential estimation, as discussed in this section. The idea of this third model run is to determine the extent to which a modified version of discrete sequential estimation causes the second model run to develop eddy activity in phase, and with the same amplitude, as that observed in the initial model control run.

Further numerical experiments will then be conducted to reduce the computational intensity required to accomplish this agreement between later model runs and the initial control run. First, as already indicated, the procedure outlined in this text is applied, simplifying the approach by restricting sequential estimation to time only. Second, further simplifying assumptions are tested, involving the manner in which the covariance matrices are updated. Third, increasing the updating interval to 7 days, 15 days and 30 days, as opposed to when each exact repeat orbit of GEOSAT occurs, is tested. In each of these model experiments, the quantitative measure of model convergence to the observations (i.e., the initial model control run) versus the computational requirements to accomplish this is of major concern. It is to be demonstrated that successive modifications of discrete sequential estimation produces essentially the same level of convergence but with increasingly less computational intensity.

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Semi- Annual Report for URI.

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Scientific Activity

The modeling activity so far has had two thrust areas
(i) Basin scale modelling
(ii) Data-assimilation

(i). *Modelling*
Quasi-geostrophic models in idealized boxes and in a realistic North Pacific domain have been adapted to run on the URI computer. The 'box' models are eddy resolving, whereas, because because of computational limitations, the North Pacific model is not. The box models are so called because their computational domain is rectangular, either with rigid walls or on a periodic domain. Both gridpoint or spectral models exist. Their advantage is computational economy, allowing high resolution and many vertical layers. Their use is in developing data assimilation algorithms for realistic models, as is discussed further below. A Norh Pacific quasi-geostrophic (NPQG) model has been developed. This will be used to assimilate real data as it becomes available. (Ultimately a primitive equation model will be used, but this presents formidable technical obstacles in data assimilation in the ocean). An eight layer mversion has been spun up to statistical equilibrium using the mean Hellerman winds. Interestingly, although most of the gyre is steady, the southern flank of the subtropical gyre remains unsteady, probably due to baroclinic instability. Figure 1 shows the instantaneous streamfunctions at levels 1, 4 and 8. The next steps, almost underway, are tests of the sensitivity of the model to changes in wind input. The experimental sequence is as follows. The NPQG model is integrated to a steady state using climatological winds. Next, for the period 1975-1986 various sets of realistic wind data are used (e.g FNOC, NMC, COADS). The sensitivity of an ocean model to wind input is thereby tested. Additionally, for a given wind set, the data is combined into weekly, monthly and seasonal averages (from the daily or twice daily values). The output of the model from these inputs gives a measure of how much of the observed mesoscale variability of the ocean is due to its intrinsic variability (due to baroclinic instability and nonlinearity) and how much is due to varying wind stresses.

Other developments in modelling involve constructing or obtaining more realistic models of the California Current region. The use of nested models will always be necessary, no matter how powerful ones computers, since one is not equally interested in all parts of the ocean. Ideas regarding construction of such a model are now firm, and coding work is underway. The method allows two way communication between the high resolution model and the gyre-scale model. Resolution will be variable; we expect typically to use about a 20km grid for the California Current. The advantages of nesting are that the respective effects of local versus remote wind forcing can be assessed, and gyre scale forcing included naturally in a high resolution mesoscale model which can resolve fronts and eddies.

(ii) *Data Assimilation*
The problem of data assimilation is evidently severe for the ocean, since data cannot be expected to be regular or dense. Thus algorithms common for atmospheric modelling, for example optimal interpolation (OI) are, as it were, less than optimal for the ocean. The problem is that such schemes assume certain error covariance structures. This is fine if data is flowing regularly, but not so otherwise. Thus, such scemes may suffice when the preponderance of data comes from satellites. However, one would also wish to assimilate *in situ* data, and data from moored arrays and even tomographic arrays. Thus more general schemes, such as Kalman filtering, are appropriate. However, the full Kalman filter is so computationally expensive that one would *never* wish to implement it, even given much more powerfull computers than are availaible today, because a disproportionate effort must be expended on the error estimation. Thus one seeks approximations. We are currently exploring several approximations, which in varying degrees keep the power of the full filter or the economy of OI. The main approximation involves simplifications in updating the model error covarience matrix. Various theoretical schemes have been devised. We are now testing these using synthetic data in the the idealized box models.

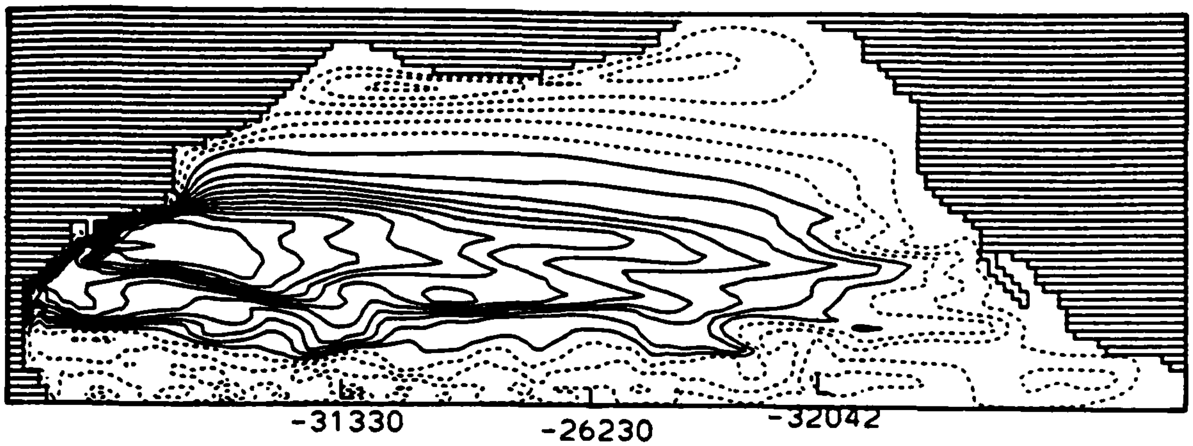
The problem of data assimilation in P.E. models is more severe, in that the gravity waves must first be suppressed, if not eliminated. In the atmosphere this is accomplished using nonlinear normal mode initialization (NNMI). However, in irregular domains one cannot easily calculate the normal modes. Hence, we are exploring other techniques. One is 'quasi-geostrophic initialization', which virtually destroys all fast waves. However, atmospheric experience has shown this is too severe and is less good than NNMI. Simply suppressing the gravity wave activity by filtering does not work, since it is found that the initial *rate of change* of the fast activity must also be eliminated if gravity waves are not to grow rapidly. Further, some gravity wave activity is probably realistic. A numerical way to suppress them may be to assimilate data over two or more model timesteps, filtering at each. Another is to project the data onto the empirical normal modes. Such ideas are very new, and we do not expect to implement them for some time. The present effort concentrates on QG models, which do not have such problems.

Financial Activity

The main equipment purchased over this period has been the Alliant mini-supercomputer, on which most of the modelling activity will be performed. Such a computer was a line item in the funded proposal. Before purchase a thorough examination of competitive machines was performed, and the Alliant chosen on the basis of speed, modularity and operating system. Because not all the money available for the hardware purchase was available in the first year, a smaller system than ultimately will be required was purchased, with the aid of a loan. The initial purchase cost of the computer was $ 550,000. A loan for this amount was taken out from First Interstate Bank, at a rate of interest of 7.75%, with payback rate of $37,000 per quarter for the next five years. The computer has performed very well, with a minimum of down time. However, already it is saturated with modelling jobs. This slows the throughput of jobs because of the limited memory on the machine. It is expected that this will be overcome in year 2 with the addition of extra high speed memory and additional processors, enabling the effective speed to be almost doubled, for a cost of about $200,000. In addition to Alliant, two Sun workstations and a laserprinter were purchased, enabling the manipulation and display of graphical output. Both machines are already networked to the mini-supercomputer.

An experienced and fulltime system manager was hired for the Alliant for the first few months. He has since become part-time, and it is expected he will ultimately be used only on a consultative basis. His total cost thus far has been about $27,000.

CASE QGNP8L-1 S-1 DAY 7200



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CASE QGNP8L-1 S-8 DAY 7200

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